This Page Is Inserted by IFW Operations
and is not a part of the Official Record

BEST AVAILABLE IMAGES

Defective images within this document are accurate representations of the original documents submitted by the applicant.

Defects in the images may include (but are not limited to):

- BLACK BORDERS
- TEXT CUT OFF AT TOP, BOTTOM OR SIDES
- FADED TEXT
- ILLEGIBLE TEXT
- SKEWED/SLANTED IMAGES
- COLORED PHOTOS
- BLACK OR VERY BLACK AND WHITE DARK PHOTOS
- GRAY SCALE DOCUMENTS

IMAGES ARE BEST AVAILABLE COPY.

As rescanning documents *will not* correct images, please do not report the images to the Image Problem Mailbox.

THIS PAGE BLANK (USPTO)

PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : H01L 21/00

A1

(11) International Publication Number: WO 99/18602

(43) International Publication Date: 15 April 1999 (15.04.99)

(21) International Application Number: PCT/US98/20628

(22) International Filing Date: 28 September 1998 (28.09.98)

(30) Priority Data:
08/946,868 8 October 1997 (08.10.97) US

(71) Applicant: APPLIED MATERIALS, INC. [US/US]; 3050 Bowers Avenue, Santa Clara, CA 95054 (US).

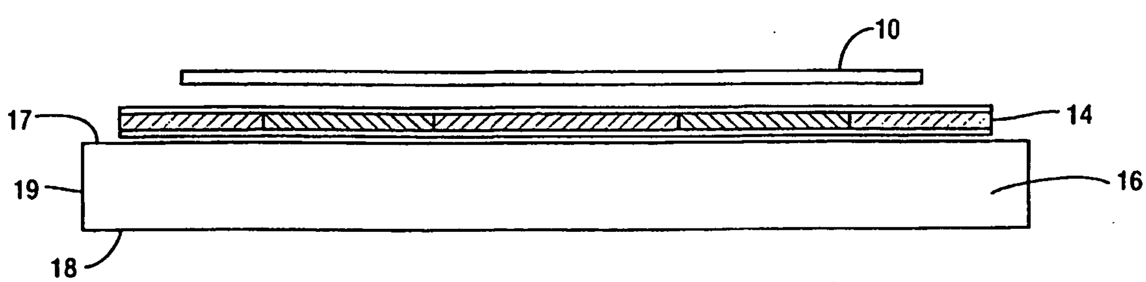
(72) Inventors: BOLANDI, Hooman; 1540 Vista Club Circle #204, Santa Clara, CA 95054 (US). YOUNG, Douglas; 147 N. Murphy Avenue, Sunnyvale, CA 94087 (US). EL-AWADY, Khalid; P.O. Box 9747, Stanford, CA 94309 (US). OCANADA, Ivan; 2535 Shilshone Circle, San Jose, CA 95121 (US).

(74) Agents: BERNADICOU, Michael, A. et al.; Blakely, Sokoloff, Taylor & Zafman LLP, 7th floor, 12400 Wilshire Boulevard, Los Angeles, CA 90025 (US).

(81) Designated States: JP, KR, SG, European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

Published
With international search report.
Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.

(54) Title: FOAM-BASED HEAT EXCHANGER WITH HEATING ELEMENT



(57) Abstract

Methods and apparatuses for providing thermal cycling applied to a material substrate are provided. A thermal cycling module comprises a heat exchanger, and additionally may comprise a heating element and a power source. The heat exchanger and the heating element are in thermal contact with the substrate, and the heating element is in electrical contact with the power source. The heat exchanger comprises an upper surface, a lower surface and a perimeter surface and an isotropic porous material interposed between the upper and lower surfaces. It also comprises a fluid introducing body that is in fluid communication with the porous material generally near the perimeter surface or generally at the center of the lower surface and a fluid outlet generally located at the center of the lower surface or near the perimeter surface that is also in fluid communication with the porous material. The module bakes and chills a substrate by flowing fluids of different temperatures generally radially through the isotropic porous material and adjusting the temperature of the heating element according to a preprogrammed cycle.

BNSDOCID: <WO 9918602A1 I >

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania	**ES**	Spain	**LS**	Lesotho	**SI**	Slovenia
AM	Armenia	**FI**	Finland	**LT**	Lithuania	**SK**	Slovakia
AT	Austria	**FR**	France	**LU**	Luxembourg	**SN**	Senegal
AU	Australia	**GA**	Gabon	**LV**	Latvia	**SZ**	Swaziland
AZ	Azerbaijan	**GB**	United Kingdom	**MC**	Monaco	**TD**	Chad
BA	Bosnia and Herzegovina	**GE**	Georgia	**MD**	Republic of Moldova	**TG**	Togo
BB	Barbados	**GH**	Ghana	**MG**	Madagascar	**TJ**	Tajikistan
BE	Belgium	**GN**	Guinea	**MK**	The former Yugoslav Republic of Macedonia	**TM**	Turkmenistan
BF	Burkina Faso	**GR**	Greece			**TR**	Turkey
BG	Bulgaria	**HU**	Hungary	**ML**	Mali	**TT**	Trinidad and Tobago
BJ	Benin	**IE**	Ireland	**MN**	Mongolia	**UA**	Ukraine
BR	Brazil	**IL**	Israel	**MR**	Mauritania	**UG**	Uganda
BY	Belarus	**IS**	Iceland	**MW**	Malawi	**US**	United States of America
CA	Canada	**IT**	Italy	**MX**	Mexico	**UZ**	Uzbekistan
CF	Central African Republic	**JP**	Japan	**NE**	Niger	**VN**	Viet Nam
CG	Congo	**KE**	Kenya	**NL**	Netherlands	**YU**	Yugoslavia
CH	Switzerland	**KG**	Kyrgyzstan	**NO**	Norway	**ZW**	Zimbabwe
CI	Côte d'Ivoire	**KP**	Democratic People's Republic of Korea	**NZ**	New Zealand		
CM	Cameroon			**PL**	Poland		
CN	China	**KR**	Republic of Korea	**PT**	Portugal		
CU	Cuba	**KZ**	Kazakstan	**RO**	Romania		
CZ	Czech Republic	**LC**	Saint Lucia	**RU**	Russian Federation		
DE	Germany	**LI**	Liechtenstein	**SD**	Sudan		
DK	Denmark	**LK**	Sri Lanka	**SE**	Sweden		
EE	Estonia	**LR**	Liberia	**SG**	Singapore		

FOAM-BASED HEAT EXCHANGER WITH HEATING ELEMENT

FIELD OF THE INVENTION

This invention relates generally to methods and apparatuses for providing thermal cycling applied to material substrates. More particularly, it relates to a heat exchanger and a thermal cycling module having improved fluid dispersement and structural design for providing controlled thermal cycling of material substrates such as semiconductor wafers and flat panel displays.

BACKGROUND OF THE INVENTION

Certain stages of semiconductor manufacturing require baking the semiconductor substrate material, such as a wafer, and subsequently chilling it. For example, the photoresist processing stage of semiconductor manufacturing requires such baking and chilling, or thermal cycling. In order to produce high quality wafers suitable for present integrated circuit applications, the temperature of the wafer during this thermal cycling must be precisely controlled with respect to both the temporal temperature profile of the baking and chilling cycles and to the uniformity of the temperature across the substrate.

The conventional method for baking and chilling wafers involves first baking the wafer at a temperature ranging typically between 70° C and 270° C for a period of time ranging typically between 30 seconds and 90 seconds. After baking the wafer, the wafer is mechanically moved to a cold plate where it is chilled to a temperature ranging typically between 0° C and 30° C.

There are several disadvantages of the above method. First, moving a wafer through the air between the hot and cold plates subjects the wafer to uncontrolled temperature variations during the bake and chill cycles. Moreover, the time required to move the wafer between the bake and chill plates prevents the realization of very short

thermal transition times. Finally, mechanically moving the wafer from the hot plate to the cold plate can contaminate or otherwise damage the wafer.

Attempts have been made to overcome the disadvantages of separate bake and chill plates. One apparatus places the hot plate upside down and directly above the cold plate. Because the wafer moves only a short distance from the cold plate directly upward to the hot plate, the apparatus reduces the uncontrolled and nonuniform temperature fluctuations normally present during the transition from the baking step to the chilling step. Nevertheless, because the wafer must be moved between separate bake and chill plates, the wafer is still subjected to uncontrolled and nonuniform temperature fluctuations during thermal cycling. Moreover, physical movement inhibits short thermal transition times. Finally, the wafer may still be exposed to contaminates or otherwise damaged during the physical movements from the hot plate to the cold plate.

Accordingly, the present invention provides an improved apparatus and method for the thermal cycling of material substrates such as wafers used in the manufacture of semiconductors. In particular, the present invention provides an improved apparatus for thermal cycling that eliminates the need to move the substrate between distinct bake or chill plates, provides improved continuous control of substrate temperature throughout the entire baking and chilling cycle and provides uniform temperature profiles on the baking and chilling surface. Further features and advantages of the invention will be apparent from the following description and drawings.

SUMMARY OF THE INVENTION

The present invention provides a single thermal cycling module for both baking and chilling a substrate, such as a wafer, that is in thermal contact with a heating element and a heat exchanger. Because the substrate is not moved during the entire baking and chilling cycles, the invention avoids problems associated with the transfer of the substrate between separate bake and chill surfaces.

The thermal cycling module of the present invention includes a heat exchanger. The heat exchanger comprises upper, lower and perimeter surfaces, at least one fluid

introducing body and an isotropic porous material, such as an aluminum alloy or other metallic foam, for dispersing thermally conductive fluid through the heat exchanger in a uniform radial manner. The fluid introducing body introduces fluid generally around the perimeter of the heat exchanger or generally at the center of the heat exchanger and the isotropic porous material causes the fluid to generally evenly disperse in all directions thus creating a generally radial flow in toward the center of the heat exchanger or out toward the perimeter.

If fluid is introduced at the perimeter of the heat exchanger, in order to ensure that it enters the isotropic porous material uniformly, the fluid introducing body can be a single fluid conducting channel generally near the perimeter of the heat exchanger having fluid-openings that may vary in size to equalize mass flow rates through all of the fluid-openings or having fluid dispersing caps that comprise a plurality of fluid-openings of different sizes and facing different directions to laterally direct fluid and maintain an axi-symmetric velocity across the heat exchanger. Additionally, the fluid introducing body can be a housing that directs fluid to the perimeter of the heat exchanger. Then, on the lower surface of the heat exchanger, generally near its center, is a fluid-outlet or drain. Thermally conductive fluid is introduced around the perimeter of the heat exchanger, flowed through the isotropic porous material and drained at the center of the heat exchanger to achieve a radial flow and an axi-symmetric temperature profile across the heat exchanger and, accordingly, the baking and chilling surface.

If fluid is introduced at the center of the heat exchanger, the fluid introducing body can be in fluid communication with the isotropic porous material through a single fluid-opening or a plurality of fluid-openings at the center of the heat exchanger or through a fluid dispersion cap. Then, generally near the perimeter of the heat exchanger on its lower surface is a single continuous fluid-outlet or drain or a plurality of fluid-outlets or drains. Thermally conductive fluid is introduced at the center of the heat exchanger, flowed through the isotropic porous material and drained around the perimeter of the plate to achieve a uniform radial flow and a radially symmetric temperature profile across the heat exchanger and, accordingly, the baking and chilling surface.

To improve the precision and uniformity of the substrate's temperature, the thermal cycling module of the present invention may further comprise a heating element. The heating element is in thermal contact with the substrate and may be placed between the heat exchanger and the substrate. Alternatively, it can be placed around, below or within the surface of the heat exchanger. The heating element may be comprised of several zones or may be one single zone. Because the heating element may be quickly and precisely adjusted to heat the substrate, it improves the control of the substrate temperature and provides for shortened temperature transition times. Moreover, if the heating element has several zones, independently controlling the zones of the heating element allows for compensation of spatial nonuniformities in substrate temperature that might arise. Alternatively, such independent control can provide intentional temperature nonuniformities if desired for special processing purposes.

BRIEF DESCRIPTION OF THE DRAWINGS

The advantages, features and design of the invention will become apparent from the following detailed description of the invention and the accompanying drawings in which like reference numerals refer to like elements and in which:

Fig. 1 is a side view of an embodiment of the thermal cycling module of the present invention;

Fig. 2 is a horizontal cross section view of an embodiment of the heat exchanger of the present invention;

Fig. 2A is a horizontal cross section view of an alternative embodiment of the heat exchanger of the present invention;

Fig. 2B is a horizontal cross section view of an alternative embodiment of the heat exchanger of the present invention;

Fig. 3 is a cross section view of the embodiment in Fig. 2 of the heat exchanger of the present invention;

Fig. 3A is a cross section view of the embodiment in Fig. 2A of the heat exchanger of the present invention;

Fig. 3B is a cross section view of an alternative embodiment of the heat exchanger of the present invention;

Fig. 4 is a bottom view of an embodiment of the fluid conducting channel in the heat exchanger of the present invention;

Fig. 5A is a vertical cross section view of an alternative embodiment of the fluid introducing body of the present invention;

Fig. 5B is a bottom view of an alternative embodiment of the fluid introducing body of the present invention;

Fig. 6 is an exploded view of an alternative embodiment of the heat exchanger and fluid introducing body of the present invention;

Fig. 7A is a side view of an embodiment of the fluid dispersion cap of the present invention;

Fig. 7B is a top view of an embodiment of the fluid dispersion cap of the present invention;

Fig. 7C is a top view of an alternative embodiment of the fluid dispersion cap of the present invention;

Fig. 7D is a top view of an alternative embodiment of the fluid dispersion cap of the present invention;

Fig. 7E is a top view of an alternative embodiment of the fluid dispersion cap of the present invention;

Fig. 7F is a top view of an alternative embodiment of the fluid dispersion cap of the present invention;

Fig. 8 is a top view of the zones of an embodiment of the zoned foil heater used in conjunction with the present invention;

Fig. 8A is a top view of the lines of an embodiment of a zoned foil heater used in conjunction with the present invention;

Fig. 9 is a chart reflecting the steady state substrate step responses to the zoned foil heating element of the present invention;

Fig. 10A is a chart reflecting a possible axi-symmetric temperature profile created on substrate due to the heat exchanger of the present invention alone;

Fig. 10B is a chart reflecting the relative rise in temperature of the substrate due to a zoned foil heater of the present invention; and

Fig. 10C is a chart reflecting the aggregate substrate temperature due to both the zoned foil heater and heat exchanger of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

The present invention provides a single thermal cycling module for baking and chilling a substrate, such as a wafer, that is in thermal contact with a zoned foil heating element and a heat exchanger. Because the substrate is not moved during the entire baking and chilling cycle, the invention avoids problems associated with the transfer of the substrate between separate bake and chill plates.

Referring to Fig. 1, a substrate 10, such as a semiconductor wafer, is baked and chilled through thermal contact with a thermal cycling module 12. Thermal contact includes physical proximity or direct physical contact sufficient to permit the transfer of heat. Both methods of establishing thermal contact are well known in the art and include positioning the substrate approximately .005 - .006 inches (.13 - .15 mms) from the plate, or holding the substrate directly against the plate with a vacuum line, electrostatic clamp or gravity. It will be appreciated by anyone skilled in the art that although the present description uses physical proximity thermal contact for purposes of definiteness, any of the known methods of thermal contact may be used.

The thermal cycling module comprises a heating element 14, a heat exchanger 16 and a power source (not shown). In addition, although not preferred, the thermal cycling module may also comprise a thermally conductive plate. The thermally conductive plate (not shown), if used, is positioned below the substrate 10, is in thermal contact with the heating element 14 and the heat exchanger 16, and in a preferred embodiment, sits directly above the heating element 14. If no thermally conductive plate is used, then the heating element 14 is in thermal contact with the substrate 10 and, in a preferred embodiment, rests directly below the substrate 10. Alternatively, the heating element 14 can be placed below the heat exchanger 16 or in a surface of the heat exchanger 16. A heating element also can be added around the

perimeter of the heat exchanger 16, either in addition to the previously listed heaters or on its own. The heating element 14 is electrically connected to a power source and is in thermal contact with the substrate 10.

Also in thermal contact with the substrate 10, and in a preferred embodiment, below the heating element 14, is the heat exchanger 16. The heat exchanger 16 has an upper surface 17, a lower surface 18, and an outer perimeter surface 19. In a preferred embodiment, the heating element 14 is fixedly attached to the heat exchanger, as is generally known by those skilled in the art.

The heat exchanger 16 of the present invention is designed to disperse thermally conductive fluid through the heat exchanger 16 in a generally radial manner. In a preferred embodiment, the heat exchanger 16 has a circular horizontal cross-section. A fluid introducing body introduces fluid either generally around the perimeter of the heat exchanger 16 or generally at the center of the heat exchanger 16, and an isotropic porous material causes the fluid to generally evenly disperse in all directions thus creating a generally radial flow toward either the center or the perimeter of the heat exchanger 16, respectively. The generally uniform radial fluid flow causes an axi-symmetric temperature profile across the heat exchanger, the baking and chilling surface (which is either the top of the thermally conductive plate or the top of the heating element 14 depending on whether a thermally conductive plate is used), and, accordingly, the substrate.

Referring to Figs. 2-2B and 3-3B, the heat exchanger 16 is illustrated having an isotropic porous material interposed between the upper surface 17 and the lower surface 18 of the heat exchanger 16. The material, in a preferred embodiment, is rigidly attached to the upper and lower surfaces 17 and 18 by a method such as brazing. In a preferred embodiment, the upper surface 17 of the heat exchanger 16 can be comprised of any material of relatively high thermal conductivity, such as a metal of copper or aluminum. Copper has preferable thermal properties, but aluminum is less expensive and simpler to manufacture. The lower surface 18 and perimeter surface 19 can be comprised of any material, although it is preferred to use the same material as is used for the upper surface 17.

BNSDOCID: <WO 9918602A1 I >

Referring to Fig. 2B, in addition to the isotropic porous material, interposed between and fixedly connected to the upper and lower surfaces there can be stiffeners 21. In a preferred embodiment, the stiffeners 21 extend radially from the center of the heat exchanger 16 to the perimeter, which minimizes the disturbance to the originally radially flowing fluid. In a preferred embodiment, the stiffeners 21 are brazed to the upper and lower surfaces and are composed of the same material as the upper surface 17, although they need not be. The stiffeners 21 stiffen the heat exchanger 16 to reduce warpage due to thermal cycling. The stiffeners 21 can be used with a flat upper surface 17 or a profiled or contoured upper surface 17.

The heat exchanger 16 also comprises at least one fluid introducing body. In a preferred embodiment, only one fluid introducing body is used and fluids of different properties or temperatures may be introduced to the heat exchanger 16 through it. Alternatively, to minimize energy consumption, there can be several fluid introducing bodies; one fluid introducing body for each type or temperature of fluid that needs to be introduced to the heat exchanger 16. If several fluid introducing bodies are included, then there can also be several fluid drains corresponding to the different fluids, which can be blocked off by a valve when not needed. In addition, a single fluid introducing body can be used with separate fluid-inlets and fluid-outlets for different types of fluid or fluids of different temperatures.

Referring to Figs. 2 and 3, in a preferred embodiment, a fluid introducing body 28 is located generally around the perimeter of the heat exchanger 16. The fluid introducing body 28 is in fluid communication with the isotropic porous material 20 through a continuous fluid-opening (not shown) or through a plurality of fluid-openings or inlets 22 generally evenly spaced near the perimeter of the heat exchanger 16. On the lower surface 18 of the heat exchanger 16, generally at its center, is a drain or fluid-outlet 24. Thermally conductive fluid from the fluid introducing body 28 is introduced through the fluid-openings 22. The thermally conductive fluid flows generally radially toward the center of the heat exchanger 16 (as shown by the arrows 26 of Fig. 2) where it drains out of the drain or fluid-outlet 24.

Referring to Figs. 2A and 3A, in an alternative embodiment, a fluid introducing body (not shown in Figs. 2A and 3A) is located generally at the center of the heat exchanger 16. The fluid introducing body is in fluid communication with the isotropic porous material 20 through a fluid-opening or inlet 22. On the lower surface 18 of the heat exchanger 16, generally around its perimeter, is a continuous drain or fluid-outlet (not shown) or a plurality of drains or fluid-outlets 24. The thermally conductive fluid flows generally radially from the center toward the perimeter of the heat exchanger 16 (as shown by the arrows 26 of Fig. 2A).

In general, the isotropic porous material 20 can be any material that permits radial dispersement of thermally conductive fluid throughout. In a preferred embodiment, the isotropic porous material 20 is aluminum alloy foam. It is preferred to use any material of generally high thermal conductivity, although it is not necessary. Generally, the foam is comprised of open, duodecahedronal-shaped cells connected by continuous solid metal ligaments. This structure is generally rigid, highly porous and permeable, and highly isotropic. Additionally, it has a high strength to weight ratio. The strength of the material causes the structure to be rigid, and the low mass of the material minimizes energy consumption and improves temperature transition times. Various pore sizes and densities can be chosen as well. One type of aluminum alloy foam is sold under the name DUOCEL®, manufactured by Energy Research and Generation, Inc., located in Oakland, California. Although not forming part of the present invention, the foam is manufactured by directional solidification of metal from a super-heated liquid state, in an environment of inert materials and a vacuum. The resulting material has a reticulated structure of open, duodecahedronal-shaped cells connected by continuous, solid metal ligaments. The cell-ligament matrix is completely repeatable, regular and uniform throughout. DUOCEL® is available in densities of from 3 to 20 percent in cell sizes of 10, 20 or 40 pores per inch. For the purpose of the present invention, a density of 5% and cell sizes of 10 pores per inch (.39 pores per mm) are preferred, and a preferred thickness of the isotropic porous material is generally 1/4 to 3/8 of an inch (6.35 to 9.65 mm) thick.

Referring to Fig. 3B, the upper surface 17, lower surface 18, and outer perimeter surface 19 of the heat exchanger 16 can be contoured to reduce initial large temperature nonuniformities due to the location of the fluid-openings, the changing velocity of the fluid, and the varying surface areas over which heat transfer occurs. For example, when flowing thermally conductive fluid into the heat exchanger 16 generally at the center of the heat exchanger 16, the distribution of a fixed volumetric flow rate over cylindrical surfaces of constant velocity that are small at the heat exchanger center and much larger at the heat exchanger perimeter generates a fluid velocity profile which is large at the center and much smaller near the perimeter. This coupled with the additional heat loss at the perimeter from the perimeter surface 19 and the time delay as the fluid propagates through the heat exchanger internal volume can result in initial large temperature nonuniformities on the upper surface 18 of the heat exchanger 16 following a transition from the chilling cycle to the baking cycle or vice versa. Care must be taken to ensure that these nonuniformities do not exceed the permissible values or the compensating limits of an auxiliary heater, for example, the heating element 14. One approach involves tapering the top surface so there is more mass at the heat exchanger center, as shown in Fig. 3B, thereby forcing an additional lag in the center's response.

Referring to Fig. 3B, in a preferred embodiment where fluid is introduced at the center of the heat exchanger, the upper surface 17 is thicker in the center and narrower near the outer perimeter surface 19. Near the outer perimeter surface 19, the upper surface 17 is approximately 0.144 inches (3.66 mm) thick. At the center, the upper surface 17 is approximately 0.313 inches (7.95 mm) thick. The lower surface 18 is approximately 0.125 inches (3.18 mm) thick. The lower surface 18 can be angled downward toward the center (not shown) or in a preferred embodiment can be level (as shown in Fig. 3B). By shaping and/or angling the upper and lower surfaces 17 and 18 of the heat exchanger, the local cross-sectional area normal to the fluid flow can be shaped as desired, thereby generating any desired flow velocity profile. The overall thickness of the heat exchanger, including the isotropic porous material 20, the upper surface 17 and the lower surface 18, is 5/8 of an inch (16 mm) near the perimeter surface 19 and 5/8 of an inch (16 mm) at the center if the lower surface 18 is level. Variations

of this design are numerous. For example, if fluid enters generally near the perimeter of the heat exchanger 16 and drains generally at the center, the upper surface 19 can increase in thickness from the center toward the perimeter.

Referring to Fig. 4, if fluid is introduced generally at the perimeter of the heat exchanger 16, the fluid introducing body 28 can comprise a fluid conducting channel 44 located generally at the perimeter of the heat exchanger 16 and having a fluid-inlet 40. A plurality of fluid-openings 22 are generally located at equal intervals along the fluid introducing body 28 to facilitate fluid communication between the fluid introducing body and the isotropic porous material 20. The fluid-openings 22 can vary in size to equalize mass flow rates through the openings regardless of the distance of the fluid-opening from the fluid-inlet 40. A blocking member 42, although not necessary, can be included across the fluid introducing body 28 to cause the fluid to flow in one direction around the heat exchanger 16. In a preferred embodiment of the channel, there is a blocking member 42, and the fluid-openings increase in size as they increase in distance from the fluid-inlet 40.

Referring to Figs. 5A and 5B, where fluid is introduced generally at the perimeter of the heat exchanger, the fluid introducing body, in a preferred embodiment, can alternatively be comprised of a first fluid conducting channel 58 located generally at the perimeter of the heat exchanger 16 and a plurality of second fluid conducting channels 50 in fluid communication with the first fluid conducting channel 58. Preferably, there are three second fluid conducting channels. The second fluid conducting channels meet at a common center fluid inlet 54 and extend radially outward and upward until they connect with the first fluid conducting channel 58. The first and second fluid conducting channels are in fluid communication through a hole or inlet 56. A plurality of fluid-openings 22 are generally located at equal intervals along the fluid introducing body to facilitate fluid communication between the first fluid conducting channel 58 and the isotropic porous material 20. The fluid-openings 22 can vary in size to equalize mass flow rates through the openings. Blocking members 51 can also be placed around the first fluid conducting channel 58 to cause fluid to flow in one direction. Fluid flows into the second fluid conducting channels 50 at the common

center fluid inlet 54. It then flows to the first fluid conducting channel 58 through the holes or inlets 56. Finally, the fluid enters the isotropic porous material 20 through the fluid openings 22 and flows radially to drain generally at the center of the lower surface 18 of the heat exchanger 16 through a fluid exiting body 52. This embodiment of the fluid introducing body is preferably made of a plastic material to minimize its mass or another good insulator, although any material can be used. Additionally, the fluid introducing body shown in Figs. 5A and 5B can be used in reverse if fluid is introduced generally at the center of the heat exchanger 16 and drained generally at the perimeter of the heat exchanger 16.

Referring to Fig. 6, where fluid is introduced generally near the perimeter of the heat exchanger, the fluid introducing body can alternatively be comprised of a first housing 64 and a second housing 68. The first housing 64 has an upper housing surface 62 that is integrally formed with the lower surface 18 of the heat exchanger 16. The first housing also has a housing perimeter surface 61, and inner channel surface 67 and a lower housing surface 66. Interposed between the upper housing surface 62 and lower housing surface 66 are walls 65 that extend from the housing perimeter surface 61 toward the center of the housing. The upper housing surface, lower housing surface 66, perimeter surface 61, inner channel surface 67, and walls 65 are all fixedly connected to one another as shown in Fig. 6, preferably by a method such as brazing. Additionally, in a preferred embodiment the housing surfaces and the walls are made of the same material as the heat exchanger upper surface 17 and lower surface 18.

The second housing 68 of the fluid introducing body shown in Fig. 6 defines two channels. The first channel in is fluid communication with the channel defined by the inner channel surface 67 of the first housing 64. The inner channel surface 67 is in turn in fluid communication with the isotropic porous material 20 of heat exchanger 16 through the fluid-outlet or drain 24 in the lower surface 18 of the heat exchanger 16. This permits thermally conductive fluid to drain from the isotropic porous material 20 through the center of the heat exchanger 16. The second channel defined by the second housing 68 is in fluid communication with the first housing 64 through a plurality of fluid-inlets 60 located generally near the inner channel surface 67 in the lower housing

surface 96 of the first housing 64. The first housing 64 is also in fluid communication with the isotropic porous material 20 through a plurality of fluid-openings 22 in the upper housing surface 62 and lower surface 18 of the heat exchanger 16, generally near the heat exchanger perimeter surface 19. Thermally conductive fluid enters the second housing 68 through an opening and then enters the first housing 64 through the fluid-inlets 60. The fluid then flows generally radially outward, guided by the plurality of walls 65 towards the perimeter housing surface 61. When the fluid reaches the perimeter housing surface 61, it flows into the isotropic porous material 20 through the fluid-openings 22. Eventually, the fluid flows back to the center of the isotropic porous material 20 and then drains through the fluid-outlet or drain 24 through the channel formed by the inner channel surface 67 and then out through the first channel of the second housing 68.

As part of the fluid introducing body shown in Fig. 6, there also can be pin lift holes 63 that are used to orient the first housing 64 and the heat exchanger 16 or that can be used to provide access through the fluid introducing body into the heat exchanger 16. Additionally, the fluid introducing body shown in Fig. 6 can be used in reverse if fluid is introduced generally at the center of the heat exchanger 16 and drained generally at the perimeter of the heat exchanger 16.

Referring to Figs. 7A-7E, where fluid is introduced at the perimeter of the heat exchanger 16, in an alternative embodiment, instead of fluid-openings, fluid dispersing caps 70 can be fixedly connected to the fluid introducing body 28. The fluid dispersion caps 70 extend upward into the isotropic porous material and are in fluid communication with the fluid introducing body and isotropic porous material. The dispersing caps 70 can be evenly spaced around the channel 28 and can have fluid cap openings 72 of various sizes that direct fluid in various directions. This causes fluid to disperse laterally before radially draining toward the fluid-outlet or drain 24 of the heat exchanger 18. Figs. 7A and 7B show one embodiment where the fluid cap openings 72 that direct fluid laterally are larger in size than the fluid cap openings 72 that direct fluid radially. In a preferred embodiment, there are two fluid cap openings 72 at a 140°

angle, as shown in Fig. 7C, which improves the radial symmetry of the temperature profile as the fluid disperses generally radially toward the center of the heat exchanger 16 at a generally axi-symmetric velocity. In an alternative embodiment the caps may have only one fluid cap openings 72. The one cap opening can direct the fluid toward the perimeter surface 19 of the heat exchanger, as shown in Fig. 7D, or it can laterally direct fluid in one direction, either clockwise or counter-clockwise, as shown in Fig. 7E.

Referring to Fig. 7F, where fluid is introduced at the center of the heat exchanger 16, a fluid dispersion cap 70 may also be used. As with respect to Figs. 7A-7E, the fluid dispersion cap 70 can be fixedly connected to the fluid introducing body, extends upward into the isotropic porous material generally at the center of the heat exchanger, and is in fluid communication with the fluid introducing body and the isotropic porous material. A plurality of fluid cap openings 72 surround the fluid dispersion cap 70. The fluid cap openings 72 can be of the same size and evenly spaced, as shown in Fig. 7F, or they can very in size and not be evenly spaced. The fluid flows radially outward from the fluid dispersion cap 70 as shown by the arrows 76 in Fig. 7F. The fluid dispersion cap 70 for the center of the heat exchanger also comprises a top surface 74. The top surface 74 prevents fluid from impinging onto the lower surface 18 of the heat exchanger 16. Impinging has a very high heat transfer coefficient relative to tubular or flow between plates, which would adversely affect the temperature profile across the substrate 10. By including the top surface 74 and the fluid cap openings 72, when fluid is introduced from the center of the heat exchanger 16 it will be forced to flow laterally rather than impinging onto the lower surface 18 of the heat exchanger. A top surface can be included in any embodiment of the fluid dispersion cap, such as those shown in Figs. 7A-7E, to prevent impinging wherever fluid is introduced to the heat exchanger 16.

It will be appreciated by anyone skilled in the art that although the present description includes only a few examples of a fluid introducing body, any known method of introducing fluid near the perimeter or near the center of an apparatus may be used. For example, individual pipes can be placed in fluid communication with the isotropic porous material 20 through fluid-openings 22 or fluid dispersion caps 70.

Similarly, if fluid is introduced at the perimeter of the heat exchanger 16, a continuous fluid-opening around the perimeter of the heat exchanger 16 could be employed.

Any type of thermally conductive fluid can be used to flow through the fluid introducing body 28 and isotropic porous material 20, but the preferred fluids are water for low temperatures or ethylene glycol, propylene glycol, or FLUORINERT, ™ which is manufactured by Minnesota Mining & Manufacturing Corporation of St. Paul, Minnesota, for higher temperature applications. The temperature of the substrate 10 is typically determined largely by the temperature of the fluid flowing through the heat exchanger 16, although this is not necessarily the case.

The heating element 14 of the present invention improves the control and uniformity of the substrate's temperature and/or decreases temperature transition times. The heating element 14 is in thermal contact with the substrate or, if one is used, with the thermally conductive surface. The heating element, preferably, is fixedly connected to the upper surface 17 of the heat exchanger 16. Alternatively, it can be placed around the perimeter surface 19, below the lower surface 18, or imbedded in any of the surfaces of the heat exchanger 16. The heating element can be comprised of a plurality of zones. Any type of heating element can be used. For example, a flexible or foil heater, thermoelectric devices, a cable heater, a cartridge heater or a cast-in heater are acceptable. Alternatively, for some applications, the thermal cycling module may not require a heating element in addition to the heat exchanger.

Referring to Figs. 8 and 8A, in a preferred embodiment, the heating element is a zoned foil heater 80 having three concentric zones 82, 84 and 86. The zoned foil heater is fixedly attached to the heat exchanger. Preferably it is attached with an adhesive, as is generally known in the art. Because the zones of the zoned foil heater 80 may be quickly and precisely adjusted to heat the plate, they can improve the control of the plate temperature and provide for shortened temperature transition times. Moreover, independently controlling the zones of the zoned foil heater 80 allows for compensation of spatial nonuniformities in substrate temperature that might arise. Alternatively, such

independent control can provide intentional temperature nonuniformities if desired for special processing purposes.

In a preferred embodiment, the zoned foil heater 80 comprises an upper layer and a lower layer. Both layers are preferably formed from an insulating material, such as KAPTON®, manufactured by E. I. DuPont de Nemours of Wilmington, Delaware. Alternative insulating layers include silicon rubber, mica, or NOMEX®, also manufactured by E.I. DuPont de Nemours. Coils, wires or lines are disposed between the upper layer and lower layer. The layers are attached to the lines with adhesive, as is generally known in the art. In a preferred embodiment, three zones are desired, so there are lines 82A, 84A and 86A, which are made of an electrically conductive material, such as tungsten or nickel-chromium, for conducting electrical current through the zoned foil heater 80. The ends of each line are electrically connected to the power source through a power modulator (not shown).

Zoned foil heater 80 preferably has a watt density of 40 W/in^2 (6.2 W/cm ^{2}). In a preferred embodiment, each of the zones 82, 84 and 86 have the same watt density. When applying full electrical excitation to any zone 82, 84 or 86, it will generate 40 W/in^2 (6.2 W/cm ^{2}) The electrical excitation applied to each zone may be varied, however, to independently generate distinct heat densities of the zones up to 40 W/in^2 (6.2 W/cm ^{2}) in order to provide intentional temperature nonuniformities and to counteract the temperature nonuniformities caused by the heat exchanger 16. Alternatively, the zones 82, 84 and 86 could have varying watt densities with variable electrical excitation across the zones, or they could have varying watt densities and each zone could be excited identically. Specific techniques for varying the watt density of a foil heater in this manner are well known in the art.

Referring to Figs. 9 and 10A-10C, the temperature profiles across the substrate's diameter due to the zoned foil heater 80 and heat exchanger 16 can be observed. These figures represent examples of the substrate response and are not necessarily typical. Fig. 9 shows the steady state temperature (in degrees C) profile along a diameter of the substrate (in millimeters) in response to a step in each of the three heater zones of 80% of full load excitation. Line 92 corresponds to zone 82, line

94 corresponds to zone 84, and line 96 corresponds to zone 86. The lines show that good separation between zones exists, as well as reasonable uniformity within any single zone. Large control authority is also present, thus making it possible for the zoned foil heating element to compensate for significant radial nonuniformities in temperature. Figs. 10A, 10B and 10C demonstrate this result. Each of Figs. 10A, 10B and 10C show the temperature profile (in degrees C) along the diameter of the substrate (in millimeters). Fig. 10A reflects a possible axi-symmetric temperature profile created on a substrate due to the heat exchanger 16 alone. Fig. 10B reflects the relative rise in temperature of the substrate due to a zoned foil heater 80. Fig. 10C reflects the aggregate substrate temperature due to both the zoned foil heater 80 and heat exchanger 16 used together.

The thermal cycling module is controlled in a preferred embodiment by a feedback control loop, which includes a multivariable feedback controller. The feedback control loop regulates the substrate temperature during the thermal cycle. Sensors are in electrical contact with a multivariable feedback controller. The sensors send to the controller electrical signals representative of substrate temperatures or process parameters of corresponding substrate regions. Each of the sensors may be a temperature or process sensor, such as a thermocouple sensor, infrared (IR) sensor or a scatterometer.

Sensors are positioned to sense particular temperatures and/or process parameters at specific regions of the substrate. For example, IR sensors may be positioned above the substrate to detect infrared radiation from particular substrate regions. Similarly, thermocouple sensors may be placed in thermal contact with the substrate to sense substrate temperatures at particular substrate regions. Techniques for sensing substrate temperatures and process parameters are well known in the art.

Based on the sensor signals, a microprocessor in the controller calculates control signals and sends them to power modulators. Each power modulator is connected to the power source and to one of the lines 82A, 84A or 86A of the zoned foil heater 80. The power modulators modulate the electrical excitation to the heating zones 82, 84 and 86. The power source varies the electrical excitation to the zoned foil heater 80 in

accordance with the control signals received from the microprocessor. Control signals for each zone 82, 84 and 86 are calculated independently based upon desired process parameters and sensor signals received from the sensors to allow one region of the substrate to be heated or cooled in a different manner than another region. The microprocessor also calculates additional temperature control signals and sends the signals to fluid supplies and to valves that control the flow of fluid through the isotropic porous material of the heat exchanger 16. The fluid then flows through the heat exchanger 16 to roughly determine the temperature of the baking and chilling surface, and in turn the substrate, over longer time periods, while the zoned foil heater 80 precisely determines local variations in the temperature at specific locations and determines the baking and chilling surface's temperature over short time intervals.

Typically, the present device is used through the specification of predetermined process parameters characteristic of the desired thermal cycle. For example, the controller may be programmed to start a substrate at 20° C and quickly ramp it up to 150° C and held for 40 seconds. After this, the substrate is chilled to 20° C and held awaiting wafer removal, the total chill time being typically 45 seconds. In this example, the controller sets fluid supplies to temperatures of 150° C and 20° C, respectively. Initially, the controller sets valves to permit only the 20° C fluid to flow from the fluid introducing body to and then generally radially through the isotropic porous material 20 of the heat exchanger 16. If any of the sensors indicate a temperature other than 20° C, then the controller sends a control signal to the power modulators and the variable power supply in order to appropriately heat or cool the appropriate plate region. In this manner, the temperature of the substrate 10 is dynamically maintained at a uniform desired temperature.

At a specified point in time, the controller begins a transition phase to ramp the temperature from 20° C to 150° C. At this point, the controller causes valves to permit only the 150° C fluid to flow from the fluid introducing body to and then generally radially through the isotropic porous material 20 of the heat exchanger 16. In order to achieve more rapid temperature response, the controller sends control signals to the

power modulators and the power source that will send currents through the zoned foil heater 80 to rapidly heat the plate. Once the sensors indicate temperatures near 150°C, the transition phase is completed and the controller begins a baking phase where a uniform temperature of 150° C is maintained through feedback in the same manner as the temperature was maintained at 20° C.

After baking the substrate for 40 seconds, the controller begins a second transition phase to ramp the temperature from 150° C to 20° C. At this point, the controller causes valves to permit only 20° C fluid to flow from the fluid introducing body to and then radially through the isotropic porous material 20 of the heat exchanger 16. The controller also sends control signals to the power modulators and the variable power supply that will send currents through the zoned foil heating element 14 to rapidly cool the plate. Once the sensors indicate temperatures of 20° C, the second transition phase is completed and the controller begins a chill phase where a uniform temperature of 20° C is maintained through feedback until the substrate is removed. Typically, the chill phase lasts 45 seconds. When the chill phase is completed, the thermal cycle is complete.

Those skilled in the art can program the controller to execute many different thermal cycles involving any number of phases and transitions of different types. Additionally, the controller can be programmed by those skilled in the art to implement the described embodiments or any variations.

Finally, the thermal cycling module 12 can also include a thermally conductive plate (not shown in any figures). The plate can be placed between the heating element 14 and the substrate 10. A preferred embodiment of the plate is approximate 0.080 inches (2.03 mm) thick and is made of aluminum, aluminum nitride or other suitable ceramic or metal. The thermally conductive plate would be in thermal contact with the heating element 14 and the heat exchanger 16. The substrate 10 would be in thermal contact with the thermally conductive plate.

WHAT IS CLAIMED IS:

1. A heat exchanger comprising:

an upper surface, a lower surface and an outer perimeter surface and an isotropic porous material defining fluid passageways interposed between said upper and lower surfaces;

a fluid introducing body in fluid communication with said isotropic porous material through at least one fluid-opening; and

said lower surface having at least one fluid-outlet that is in fluid communication with said isotropic porous material.

2. The heat exchanger of claim 1 wherein said fluid introducing body is in fluid communication with said isotropic porous material through at least one fluid-opening generally near said perimeter surface and where said fluid-outlet in said lower surface is located generally at the center of said lower surface.

3. The heat exchanger of claim 1 wherein said fluid introducing body is in fluid communication with said isotropic porous material through at least one fluid-opening generally near the center of said lower surface and wherein said fluid-outlet in said lower surface is located generally near said perimeter surface.

4. The heat exchanger of claim 2 wherein said fluid introducing body is in fluid communication with said isotropic porous material through a plurality of fluid-openings having generally equal distances between them.

5. The heat exchanger of claim 4 wherein the fluid introducing body comprises a fluid conducting channel having at least one fluid-inlet to introduce fluid to the fluid conducting channel.

6. The heat exchanger of claim 5 wherein said fluid-openings vary in size.

7. The heat exchanger of claim 4 wherein said fluid introducing body comprises a first fluid conducting channel in fluid communication with said isotropic porous material through said plurality of fluid-openings and a plurality of second fluid conducting channels in fluid communication with said first fluid conducting channel, said second fluid conducting channels receiving fluid from a common fluid inlet.

8. The heat exchanger of claim 2 wherein said fluid introducing body is in fluid communication with said isotropic porous material through a plurality of fluid-openings and wherein the heat exchanger further comprises a plurality of fluid dispersion caps in fluid communication with the fluid introducing body at each fluid-opening and with the isotropic porous material and wherein the fluid dispersion caps each define at least one fluid cap opening to facilitate fluid communication.

9. The heat exchanger of claim 8 wherein the fluid dispersion caps each define a plurality of fluid cap openings of differing sizes to vary the amount of fluid dispersed in different directions.

10. The heat exchanger of claim 8 wherein the fluid introducing body comprises a fluid conducting channel having a first end and a second end and at least one fluid-inlet to introduce fluid to the fluid conducting channel.

11. The heat exchanger of claim 10 wherein said fluid dispersing caps have generally equal distances between them.

12. The heat exchanger of claim 2 wherein said upper surface gradually decreases in thickness from said perimeter surface generally to said center of said upper surface.

13. The heat exchanger of claim 3 further comprising a fluid dispersion cap in fluid communication with said fluid introducing body at said fluid-opening and with said isotropic porous material, said fluid dispersion cap comprising a top surface and a

BNSDOCID: <WO 9918602A1 I >

plurality of fluid cap openings to facilitate fluid communication with said isotropic porous material.

14. The heat exchanger of claim 3 wherein said fluid-outlet in said lower surface comprises a continuous fluid-outlet generally near the perimeter surface and around the lower surface of said heat exchanger.

15. The heat exchanger of claim 3 further comprising a plurality of fluid-outlets in said lower surface located generally near said perimeter surface and having generally equal distances between them.

16. The heat exchanger of claim 2 wherein said fluid introducing body comprises:

a first housing having a housing perimeter surface, an inner channel surface, an upper housing surface and a lower housing surface, said upper housing surface being integral with said lower surface, said housing perimeter surface extending downwardly from and being fixedly connected to said upper housing surface, said inner channel surface extending downwardly from and being fixedly connected to said upper housing surface to define a channel below and in fluid communication with said fluid-outlet in said lower surface; and said lower housing surface being fixedly connected to said housing perimeter surface and said inner channel surface;

a plurality of walls fixedly attached to and interposed between said upper housing surface and said lower housing surface, said walls also being fixedly attached to said housing perimeter surface and extending radially inward from said housing perimeter surface;

a second housing extending downwardly from and being fixedly connected to said lower housing surface, said second housing defining a first fluid channel in fluid communication with said fluid-outlet of said lower surface through the channel defined by said inner channel surface of said

first housing and defining a second fluid channel in fluid communication with said first housing;

said lower housing surface defining a plurality of fluid-inlets near said inner channel surface to facilitate fluid communication between said first housing and the second fluid channel of said second housing; and

said upper housing surface defining a plurality of fluid-openings generally near said housing perimeter surface to facilitate fluid communication between said first housing and said isotropic porous material.

17. The heat exchanger of claim 3 wherein said upper surface gradually increases in thickness from said perimeter surface generally to the center of said upper surface.

18. The heat exchanger of claim 3 wherein said lower surface angles from said perimeter surface generally downward toward the center of said lower surface.

19. The heat exchanger of claim 1 wherein said isotropic porous material comprises open duodecahedronal-shaped cell frames connected by continuous solid ligaments to permit fluid to flow therethrough.

20. The heat exchanger of claim 1 wherein said isotropic porous material comprises aluminum alloy foam.

21. The heat exchanger of claim 1 further comprising a plurality of stiffeners fixedly connected to said upper surface and said lower surface and disposed between said upper surface and said lower surface.

22. A heat exchanger comprising:

an upper surface, a lower surface and an outer perimeter surface and an isotropic porous material defining fluid passageways interposed between said upper and lower surfaces;

a fluid conducting channel in fluid communication with said isotropic porous material, said fluid conducting channel having at least one fluid-inlet to introduce fluid to the fluid conducting channel and a plurality of fluid-openings to facilitate fluid communication between the fluid conducting channel and said isotropic porous material; and

said lower surface having a fluid-outlet generally at its center that is in fluid communication with said isotropic porous material.

23. A heat exchanger comprising:

an upper surface, a lower surface and an outer perimeter surface and an isotropic porous material defining fluid passageways interposed between said upper and lower surfaces;

a plurality of fluid dispersing caps in fluid communication with said isotropic porous material generally near said perimeter surface, said fluid dispersing caps each defining at least one fluid cap opening to facilitate fluid communication with said isotropic porous material;

a fluid introducing body in fluid communication with said fluid dispersion cap; and

said lower surface having a fluid outlet generally at its center that is in fluid communication with said isotropic porous material.

24. The heat exchanger of claim 23 wherein said fluid introducing body comprises a fluid conducting channel having at least one fluid-inlet to introduce fluid to the fluid conducting channel and a plurality of fluid-openings to facilitate fluid communication between the fluid conducting channel and said fluid dispersion caps.

25. A heat exchanger comprising:

an upper surface, a lower surface and an outer perimeter surface and an isotropic porous material defining fluid passageways interposed between said upper and lower surfaces;

a first fluid conducting channel in fluid communication with said isotropic porous material, said first fluid conducting channel having a plurality of fluid-openings to facilitate fluid communication between the fluid conducting channel and said isotropic porous material;

a plurality of second fluid conducting channels in fluid communication with said first fluid conducting channel;

said plurality of second fluid conducting channels receiving fluid from a common fluid inlet; and

said lower surface having a fluid-outlet generally at its center that is in fluid communication with said isotropic porous material.

26. A heat exchanger comprising:

an upper surface, a lower surface and an outer perimeter surface and an isotropic porous material defining fluid passageways interposed between said upper and lower surfaces;

a fluid introducing body comprising a first housing and a second housing, said first housing in fluid communication with said isotropic porous material generally near said perimeter surface through a plurality of fluid-openings in said lower surface;

said lower surface having a fluid-outlet generally at its center that is in fluid communication with said isotropic porous material;

said first housing of said fluid introducing body comprising a housing perimeter surface, an inner channel surface, and a lower housing surface, said housing perimeter surface extending downwardly from and being fixedly connected to said lower surface, said inner channel surface extending downwardly from and being fixedly connected to said lower surface to define a channel below and in fluid communication with said fluid-outlet in said lower surface; and said lower housing surface being fixedly connected to said housing perimeter surface and said inner channel surface; a plurality of walls fixedly attached to and interposed between

said lower surface and said lower housing surface, said walls also being fixedly attached to said housing perimeter surface and extending radially inward from said housing perimeter surface;

said second housing of said fluid introducing body extending downwardly from and being fixedly connected to said lower housing surface, said second housing defining a first fluid channel in fluid communication with said fluid-outlet of said lower surface through the channel defined by said inner channel surface of said first housing and defining a second fluid channel in fluid communication with said first housing; and

said lower housing surface defining a plurality of fluid-inlets near said inner channel surface to facilitate fluid communication between said first housing and the second fluid channel of said second housing.

27. A heat exchanger comprising:

an upper surface, a lower surface and an outer perimeter surface and an isotropic porous material defining fluid passageways interposed between said upper and lower surfaces;

a fluid introducing body in fluid communication with said isotropic porous material through at least one fluid-opening generally at the center of said lower surface; and

said lower surface having at least one fluid-outlet generally near said perimeter surface that is in fluid communication with said isotropic porous material.

28. A heat exchanger comprising:

an upper surface, a lower surface and an outer perimeter surface and an isotropic porous material defining fluid passageways interposed between said upper and lower surfaces;

a fluid dispersion cap in fluid communication with said isotropic porous material generally at the center of said lower surface, said fluid dispersing

BNSDOCID: <WO 9918602A1 I >

cap comprising a top surface and defining a plurality of fluid cap openings to facilitate fluid communication with said isotropic porous material;

a fluid introducing body in fluid communication with said fluid dispersion cap; and

said lower surface having at least one fluid-outlet generally near said perimeter surface that is in fluid communication with said isotropic porous material.

29. A thermal cycling module comprising:

a heat exchanger comprising an upper surface, a lower surface, an outer perimeter surface, an isotropic porous material defining passageways for fluid interposed between said upper surface and said lower surface and a fluid introducing body in fluid communication with said isotropic porous material through at least one fluid-opening in said lower surface, said lower surface having at least one fluid-outlet in fluid communication with said isotropic porous material;

a heating element in thermal contact with and fixedly connected to said heat exchanger; and

a power source in electrical contact with said zoned foil heating element.

30. The thermal cycling module of claim 29 further comprising a thermally conductive plate in thermal contact with said heating element and said heat exchanger.

31. The thermal cycling module of claim 29 wherein said fluid introducing body is in fluid communication with said isotropic porous material through at least one fluid-opening generally near said perimeter surface and where said fluid-outlet in said lower surface is located generally at the center of said lower surface.

32. The thermal cycling module of claim 31 wherein said fluid introducing body is in fluid communication with said isotropic porous material through at least one fluid-opening generally near the center of said lower surface and wherein said fluid-outlet in said lower surface is located generally near said perimeter surface.

33. The thermal cycling module of claim 31 wherein said fluid introducing body is in fluid communication with said isotropic porous material through a plurality of fluid-openings having generally equal distances between them.

34. The thermal cycling module of claim 33 wherein said fluid introducing body comprises a fluid conducting channel having at least one fluid-inlet to introduce fluid to the fluid conducting channel.

35. The thermal cycling module of claim 34 wherein said fluid-openings vary in size.

36. There thermal cycling module of claim 33 wherein said fluid introducing body comprises a first fluid conducting channel in fluid communication with said isotropic porous material through said plurality of fluid-openings and a plurality of second fluid conducting channels in fluid communication with said first fluid conducting channel, said second fluid conducting channels receiving fluid from a common fluid inlet.

37. The thermal cycling module of claim 31 wherein said fluid introducing body is in fluid communication with said isotropic porous material through a plurality of fluid-openings and wherein the heat exchanger further comprises a plurality of fluid dispersion caps in fluid communication with the fluid introducing body at each fluid-opening and with the isotropic porous material and wherein the fluid dispersion caps each define at least one fluid cap opening to facilitate fluid communication with said isotropic porous material.

38. The thermal cycling module of claim 37 wherein the fluid dispersion caps each define a plurality of fluid cap openings of differing sizes to vary the amounts of fluid dispersed in different directions.

39. The thermal cycling module of claim 37 wherein the fluid introducing body comprises a fluid conducting channel having at least one fluid-inlet to introduce fluid to the fluid conducting channel.

40. The thermal cycling module of claim 39 wherein said fluid dispersing caps have generally equal distances between them.

41. The thermal cycling module of claim 31 wherein said upper surface of said heat exchanger gradually decreases in thickness from said perimeter surface generally to said center of said upper surface.

42. The thermal cycling module of claim 32 wherein said heat exchanger further comprises a fluid dispersion cap in fluid communication with said fluid introducing body at said fluid-opening and with said isotropic porous material, said fluid dispersion cap comprising a top surface and defining a plurality of fluid cap openings to facilitate fluid communication with said isotropic porous material.

43. The thermal cycling module of claim 32 wherein said fluid-outlet in said lower surface of said heat exchanger comprises a continuous fluid-outlet generally near the perimeter surface and around the lower surface of said heat exchanger.

44. The thermal cycling module of claim 32 further comprising a plurality of fluid-outlets in said lower surface of said heat exchanger located generally near said perimeter surface and having generally equal distances between them.

BNSDOCID: <WO 9918602A1 I >

45. The thermal cycling module of claim 31 wherein said fluid introducing body comprises:

a first housing having a housing perimeter surface, an inner channel surface, an upper housing surface and a lower housing surface, said upper housing surface being integral with said lower surface of said heat exchanger, said housing perimeter surface extending downwardly from and being fixedly connected to said upper housing surface, said inner channel surface extending downwardly from and being fixedly connected to said upper housing surface to define a channel below and in fluid communication with said fluid-outlet in said lower surface of said heat exchanger; and said lower housing surface being fixedly connected to said housing perimeter surface and said inner channel surface;

a plurality of stiffeners fixedly attached to and interposed between said upper housing surface and said lower housing surface, said stiffeners also being fixedly attached to said housing perimeter surface and extending radially inward from said housing perimeter surface;

a second housing extending downwardly from and being fixedly connected to said lower housing surface, said second housing defining a first fluid channel in fluid communication with said fluid-outlet of said lower surface of said heat exchanger through the channel defined by said inner channel surface of said first housing and defining a second fluid channel in fluid communication with said first housing;

said lower housing surface defining a plurality of fluid-inlets near said inner channel surface to facilitate fluid communication between said first housing and the second fluid channel of said second housing; and

said upper housing surface defining a plurality of fluid-openings generally near said housing perimeter surface to facilitate fluid communication between said first housing and said isotropic porous material of said heat exchanger.

46. The thermal cycling module of claim 32 wherein said upper surface of said heat exchanger gradually increases in thickness from said perimeter surface generally to the center of said upper surface.

47. The thermal cycling module of claim 32 wherein said lower surface of said heat exchanger angles from said perimeter surface generally downward toward the center of said lower surface.

48. The thermal cycling module of claim 29 wherein said isotropic porous material comprises open duodecahedronal-shaped cell frames connected by continuous solid ligaments to permit fluid to flow therethrough.

49. The thermal cycling module of claim 29 wherein said isotropic porous material comprises aluminum alloy foam.

50. The thermal cycling module of claim 29 wherein the heating element is a foil heater.

51. The thermal cycling module of claim 50 wherein the foil heater comprises concentric heating zones.

52. A method of baking and chilling a material substrate, the method comprising:

placing the substrate in thermal contact with a zoned foil heating element and a heat exchanger;

exchanging heat between the zoned foil heating element and the substrate;

exchanging heat between the heat exchanger and the substrate;

introducing thermally conductive fluids to the heat exchanger;

flowing the thermally conductive fluids of differing temperatures generally radially through an isotropic porous material in the heat exchanger;

draining the thermally conductive fluids of differing temperatures from the heat exchanger;

calculating a control signal based on a desired process parameter;

changing a flow of current through the zoned foil heating element in accordance with the calculated control signal; and

changing the fluid flowing through the heat exchanger in accordance with the calculated control signal.

53. The method of baking and chilling a material substrate in claim 52 wherein the thermally conductive fluids are introduced generally near an outer perimeter of the heat exchanger and wherein the thermally conductive fluids are drained generally at the center of the heat exchanger.

54. The method of baking and chilling a material substrate in claim 52 wherein the thermally conductive fluids are introduced generally at the center of the heat exchanger and wherein the thermally conductive fluids are drained generally near an outer perimeter of the heat exchanger.

BNSDOCID: <WO 9918602A1 I >

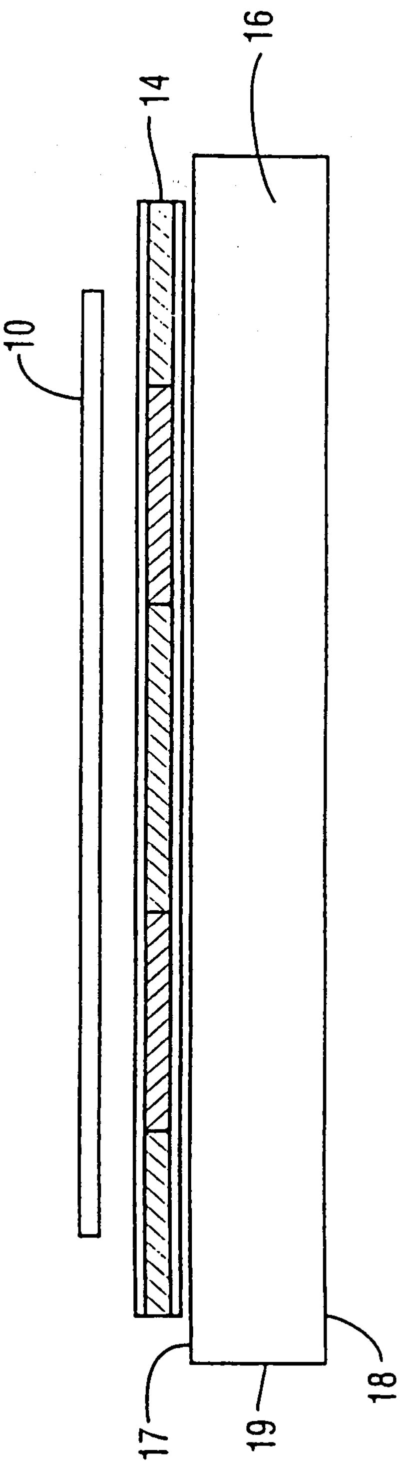


FIG. 1

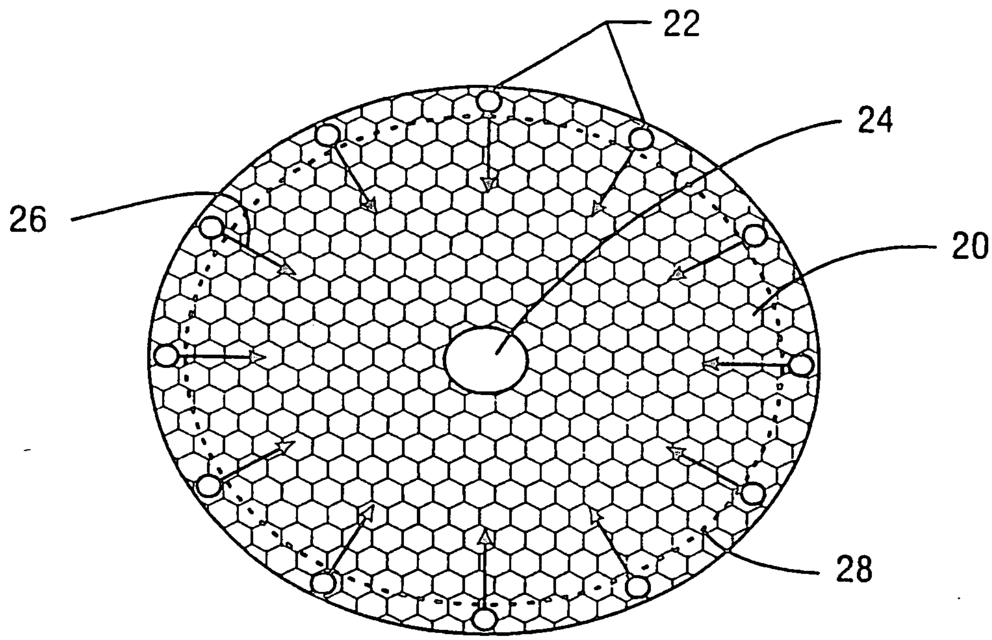


FIG. 2

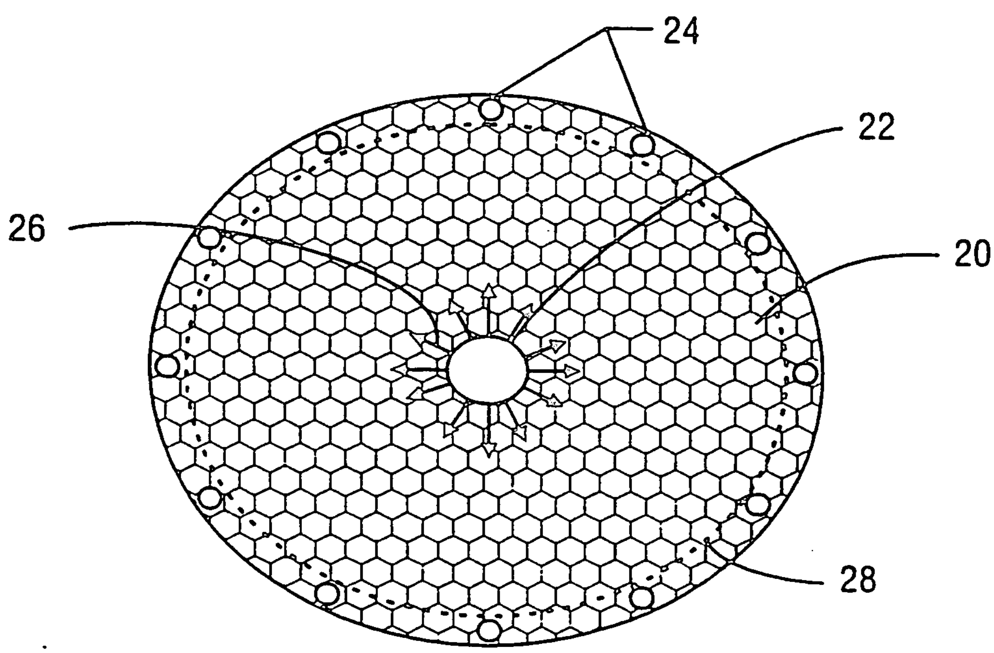


FIG. 2A

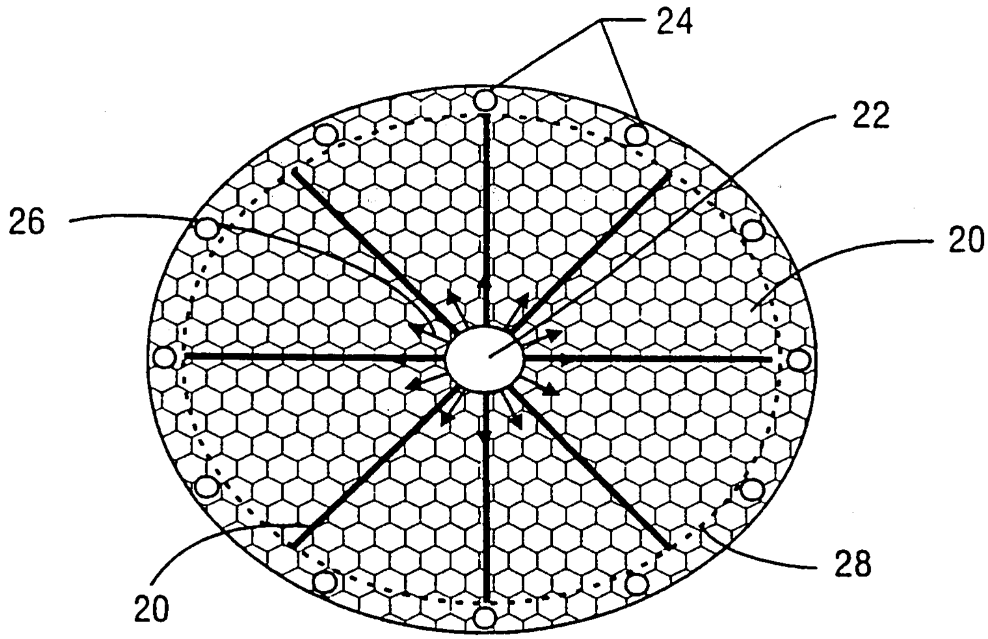


FIG. 2B

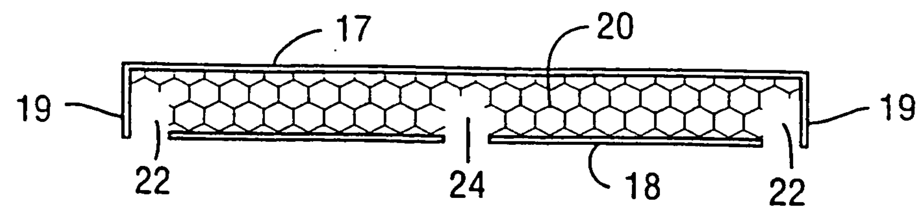


FIG. 3

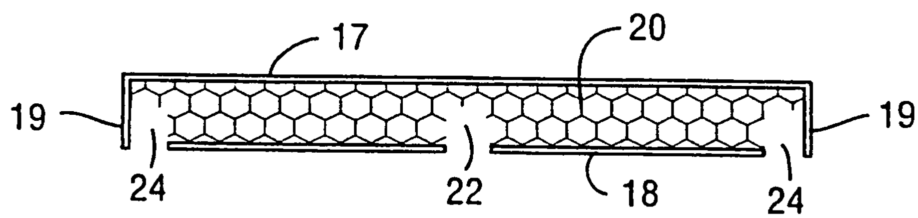


FIG. 3A

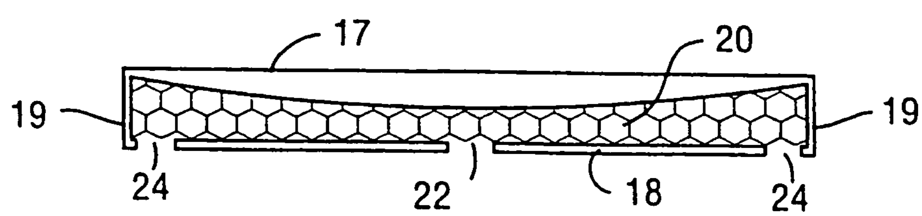


FIG. 3B

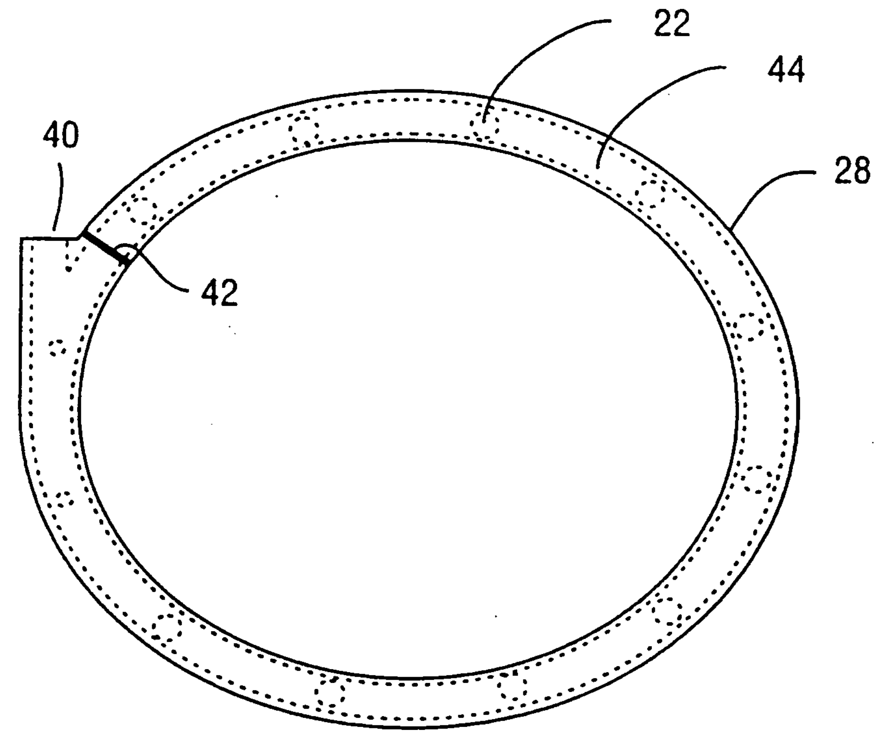


FIG. 4

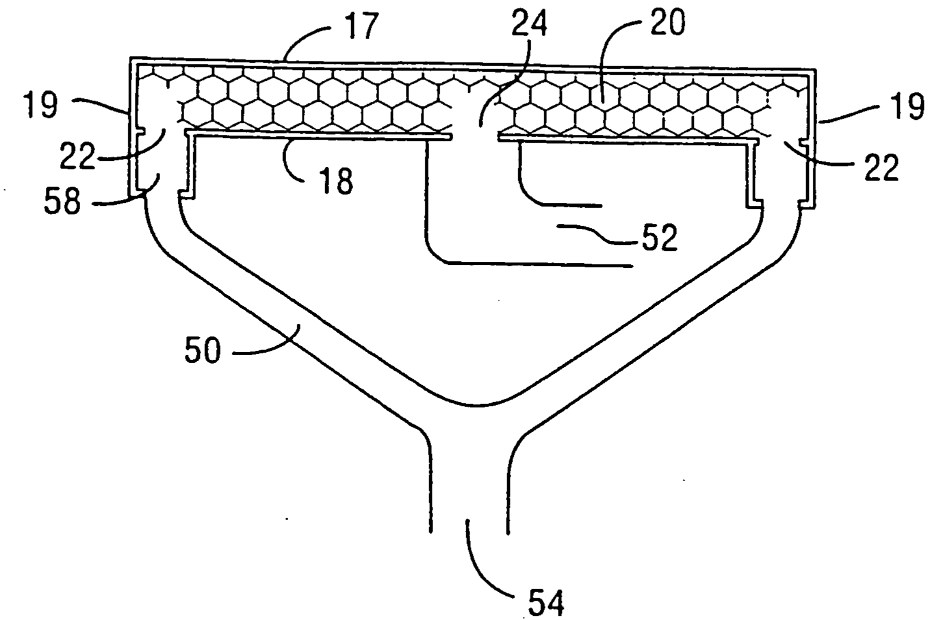


FIG. 5A

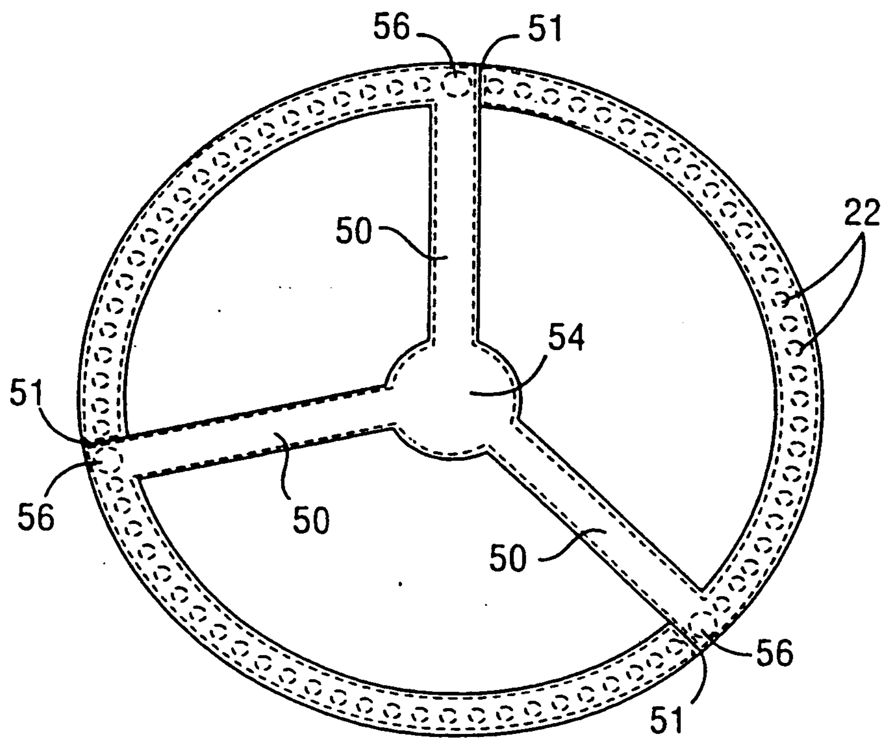


FIG. 5B

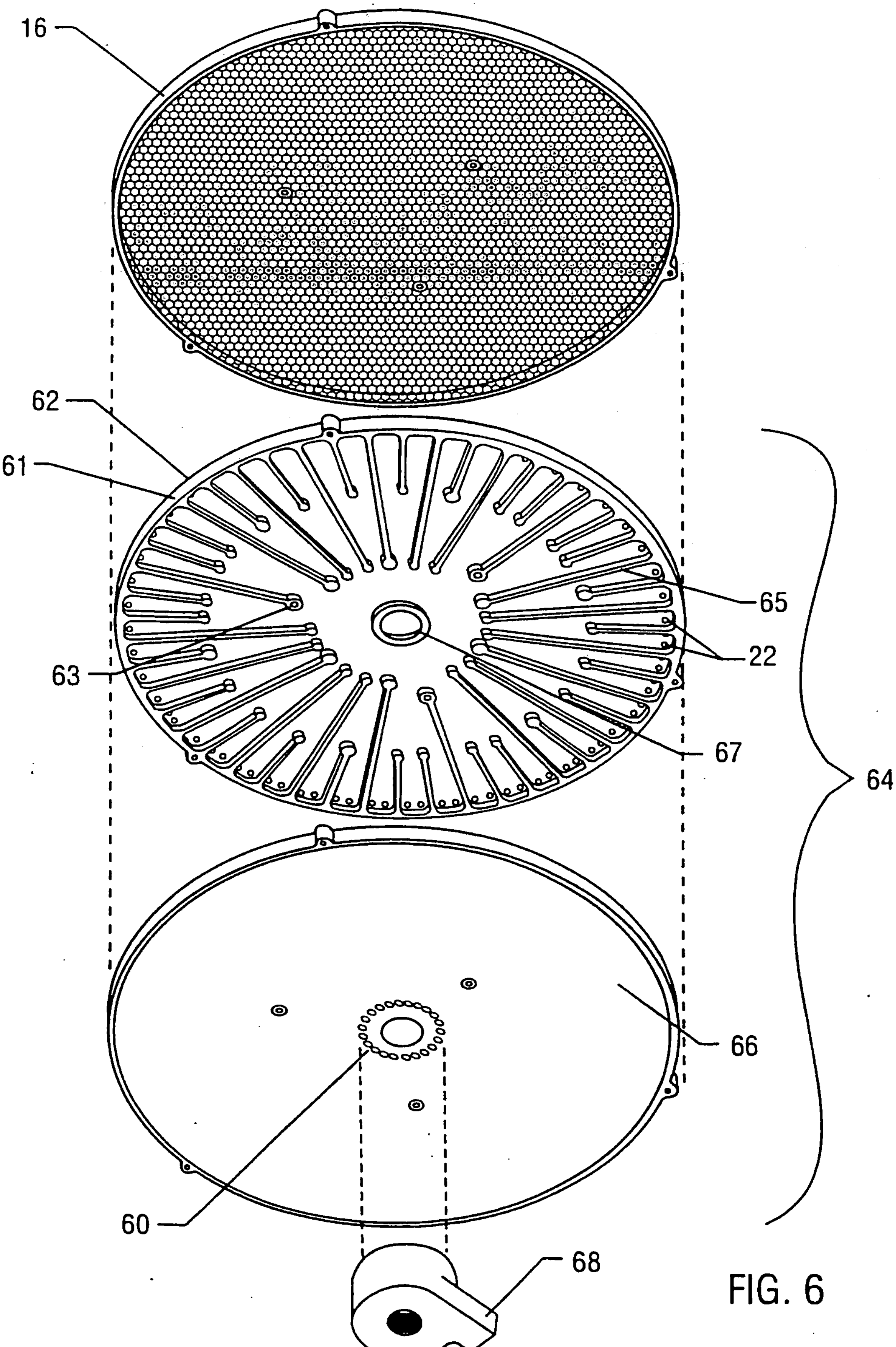


FIG. 6

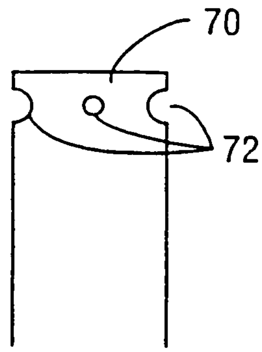


FIG. 7A

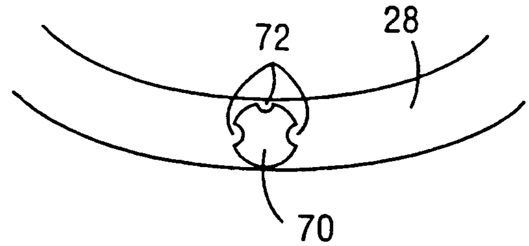


FIG. 7B

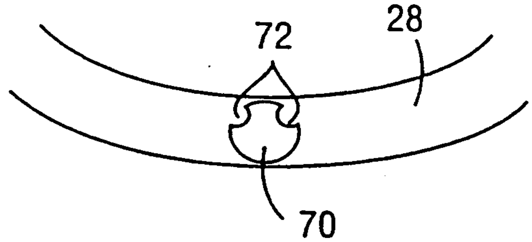


FIG. 7C

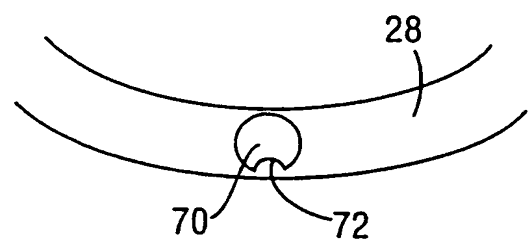


FIG. 7D

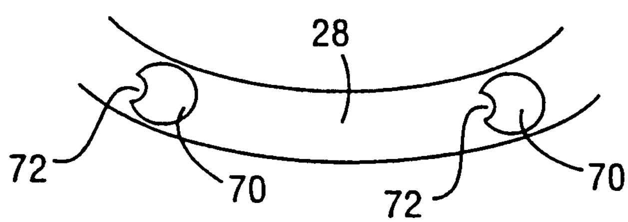


FIG. 7E

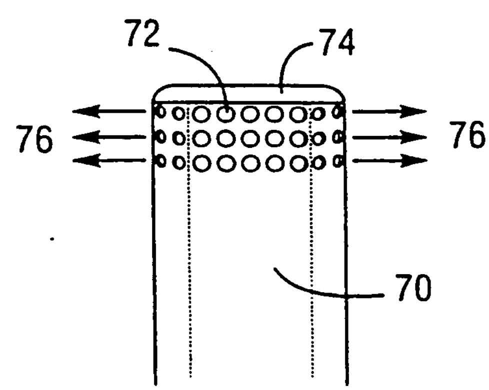


FIG. 7F

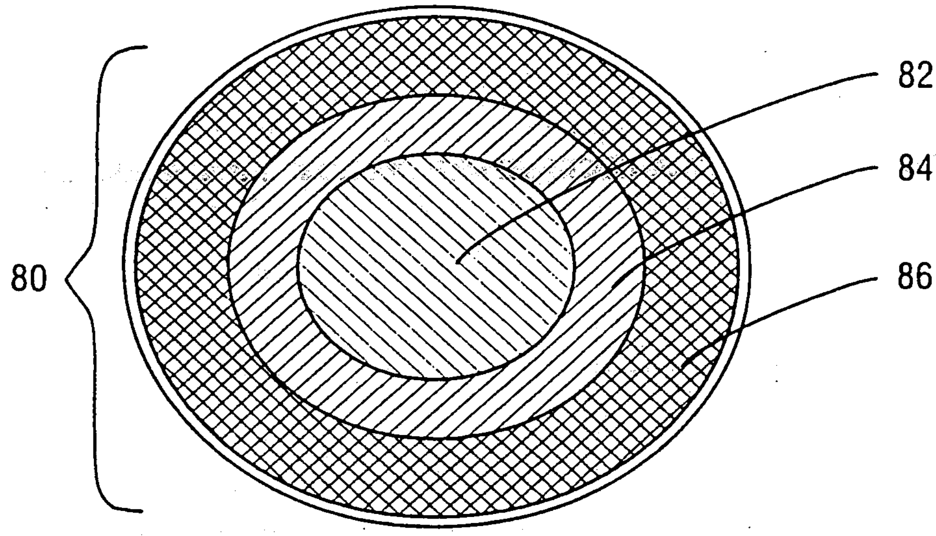


FIG. 8

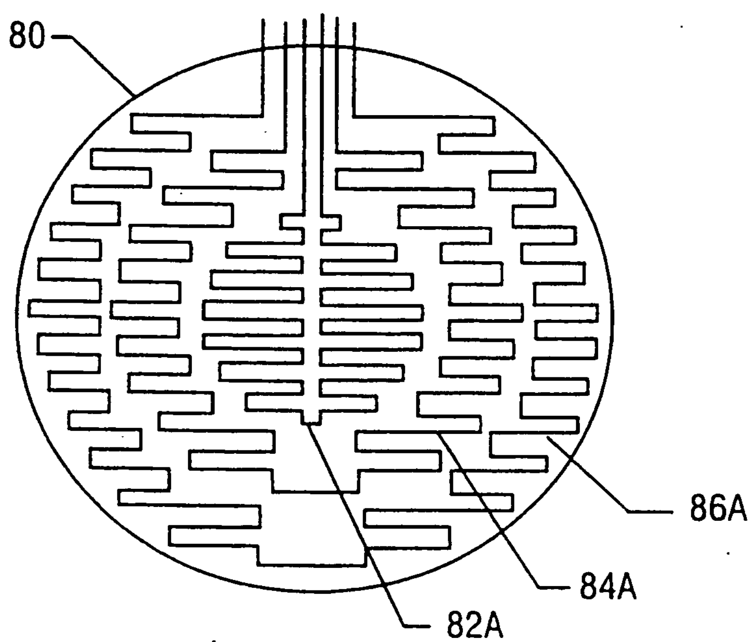


FIG. 8A

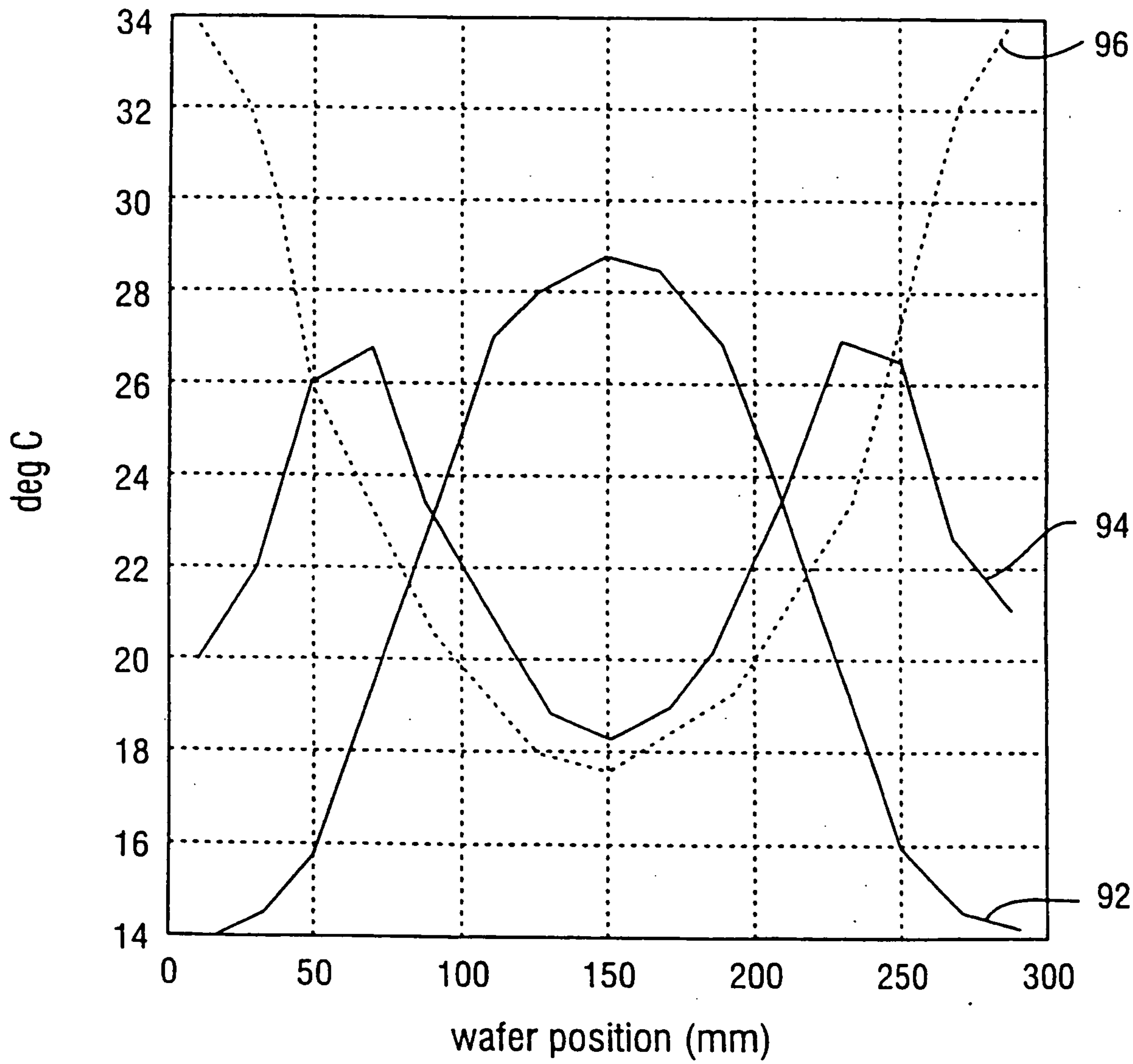

34
32
30
28
26
24
22
20
18
16
14
deg C
0
50
100
150
200
250
300
wafer position (mm)
96
94
92

FIG. 9

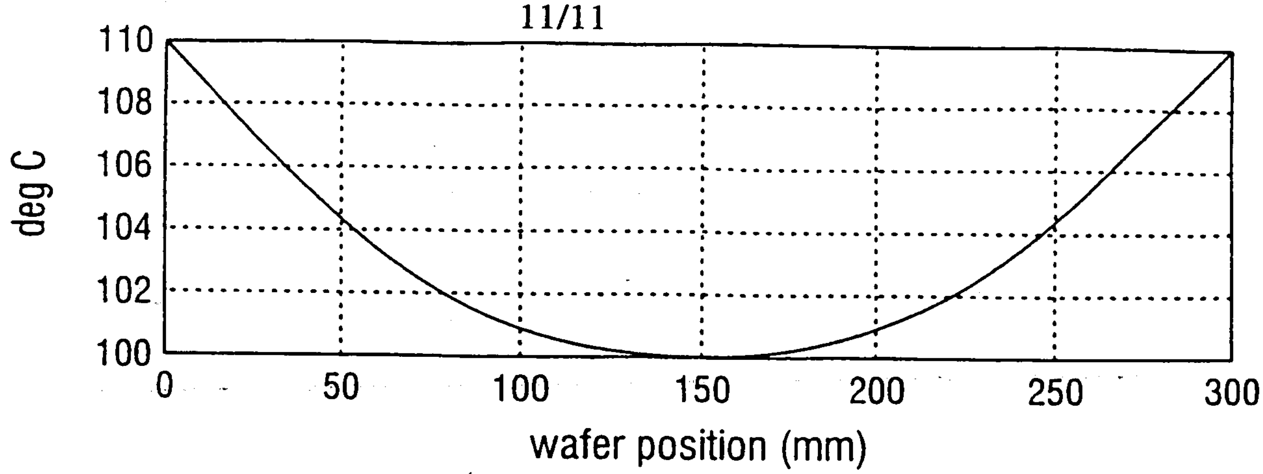


FIG. 10A

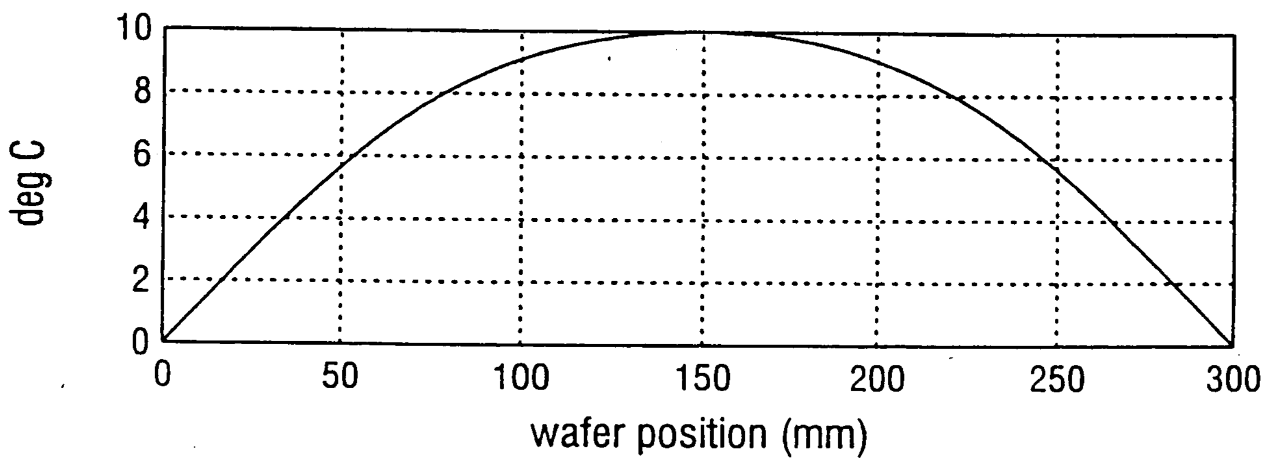


FIG. 10B

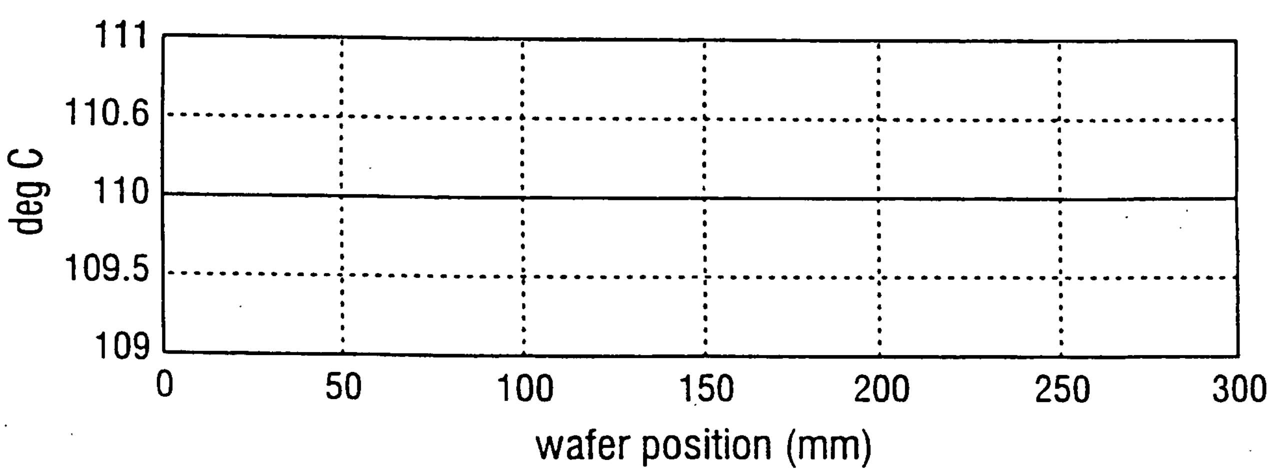


FIG. 10C

INTERNATIONAL SEARCH REPORT

Int. .tional Application No
PCT/US 98/20628

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 H01L21/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 H01L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 402 004 A (OZMAT) 28 March 1995 see abstract; figures 3,4 see column 3, line 65 - column 4, line 8 ---	1-4, 22-31,52
A	PATENT ABSTRACTS OF JAPAN vol. 015, no. 003 (E-1019), 7 January 1991 & JP 02 260411 A (SHARP CORP), 23 October 1990 see abstract -----	1,22,23, 25-29,52

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
28 January 1999	10/02/1999

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Oberle, T

1

BNSDOCID: <WO 9918602A1 I >

INTERNATIONAL SEARCH REPORT

Information on patent family members

Inte   ional Application No
PCT/US 98/20628

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5402004 A	28-03-1995	DE 69126686 D	07-08-1997
		DE 69126686 T	23-10-1997
		EP 0471552 A	19-02-1992
		JP 6120380 A	28-04-1994

THIS PAGE BLANK (USPTO)